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Sugarcane Response to High Water Tables and Intermittent Flooding

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Sugarcane production has engendered environmental concerns of nutrient transfer and subsidence of organic soils. Retaining water on fields would ameliorate these environmental issues. The objective of this research was to document the growth of sugarcane subjected to various high water-table treatments. Two experiments were conducted across two years using three sugarcane cultivars grown outdoors in large pots. Key aspects were to examine the timing of when water-table treatments were imposed and the influence of intermittent flooding. Continuous flooding at all growth stages was deleterious. A continuous water table at a 15 cm depth below the soil surface resulted in no negative effect on cane yield. Intermittent flooding in cycles of 6 d flooding, followed by 15 d at either a 15 cm or 45 cm water table, did not decrease yields. These results indicated that there may be practical management options for sustaining sugarcane production at high water tables.

KEYWORDS *intermittent flooding, soil subsidence, sugarcane, water table depth*

INTRODUCTION

Wild relatives of commercial sugarcane (*Saccharum* spp.) are naturally adapted to wetlands (Srinivasan & Batcha 1963), which is consistent with

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observations that aerenchyma are present in sugarcane roots. A study of more than 40 sugarcane genotypes revealed that all genotypes had roots with aerenchyma (Ray, Miller, & Sinclair 1996; Van Der Heyden, Ray, and Nable 1998). Aerenchyma allow oxygen to be transferred within the plant to roots that are submerged so that the root system can remain viable even in flooded conditions. Potential adaptability of sugarcane to high water tables or even flooded conditions may be an untapped attribute in sugarcane production.

Sugarcane is grown in tropical climates often subject to heavy, intense rains that flood fields. A consequence may be that these rains and subsequent drainage cause soil and nutrients to be carried from sugarcane fields into neighboring ecosystems. This situation is a concern in Australia where runoff from sugarcane fields may contribute to adverse effects on the Great Barrier Reef (Rayment 2002). If sugarcane could be managed to retain rainwater on the fields without a loss in yield, then potential infringement of nutrients into these ecosystem is likely to be greatly minimized.

In some areas where sugarcane is grown on soil of high organic matter content, there is likely another benefit of maintaining a high water table in sugarcane fields. High organic matter soils are especially vulnerable to microbial oxidation when the soil is allowed to dry. For example, sugarcane in Florida is grown on what was a marsh ecosystem drained for agricultural production in the 20th century (Snyder & Davidson 1994). The drained muck Histosols are often more than 85% organic matter (Snyder 1994). Because the commercial management objective is usually to maintain the water table at 40 to 95 cm below the soil surface (Omary & Izuno 1995), there has been widespread land subsidence. Approximately 2.5 cm of soil per year were lost from the early 1900s to 1978 (Shih et al. 1978, Synder et al. 1978; Stephens, Allen Jr., & Chen 1984). Even with altered cropping systems, subsidence was still 1.4 cm per year (Shih, Glaz, & Barnes Jr. 1998). Maintaining the soil in a wet, even water-saturated, condition could decrease oxidation and subsidence even further.

Considering the potential environmental benefits of allowing high or flooded water tables in sugarcane fields, information is needed to resolve the sensitivity of this crop to these conditions. Gilbert and colleagues (2008) found that a three-month summer flood resulted in severe yield losses. However, other studies have demonstrated that selections of sugarcane suffered no loss of yield under field conditions when the average water table was as shallow as 30 cm (Kang, Snyder, & Miller 1986), 15 cm (Glaz et al. 2002), or even when the soil is waterlogged for part of the season (Deren et al. 1991). Several sugarcane genotypes grown in pots had no significant yield decline when the water table was maintained at 15 cm rather than 30 cm through much of the season (Peter Tai, personal communication, USDA-ARS, Canal Point, FL). However, two critical concerns remain unresolved: (1) possible variation in response to timing of initiation of high water-table levels, and (2) the effects of flood duration on plant growth. The objective of this research was to examine each of these questions by carefully controlling the timing and water-table depth to which sugarcane plants were subjected through a growing season.

MATERIALS AND METHODS

Cultural Practices

Outdoor pot studies were conducted in 1999 and 2000 at the Agronomy Physiology Laboratory on the University of Florida campus in Gainesville, Florida. Large pots were constructed from 25.4 cm diameter polyvinyl chloride (PVC) pipes cut to 53 cm lengths. A piece of fiberglass mesh screen was folded over the bottom of the pipe and secured using a plastic cable tie. The pots were then placed in 568 liter plastic stock tanks situated on an open concrete slab. Tanks were spaced approximately 2.5 m center to center. Each stock tank held six of the PVC pipe pots. For the 1999 experiment, pots were filled with a commercially available sandy loam topsoil (Sunniland Corporation, Sanford, FL). For the 2000 study, a Pahokee muck soil (Euic, hyperthermic Lithic Medisaprists) was collected from the sugarcane-production area in South Florida. The soil was removed from the field in three, successive layers, each approximately 20 cm thick. The PVC pots were filled with the soil collected from each of the three layers to approximate the natural soil profile.

Each of the stock tanks had a drain located on the side about 5 cm from the bottom. Water levels were controlled by inserting a PVC pipe adapter into the drain hole and attaching a short length of 2.5 cm diameter PVC pipe with an elbow facing upwards. Into the vertical section of the elbow, 1.9 cm diameter PVC pipes of various lengths were inserted. The water level in an individual tank was controlled by varying the length of the vertical PVC pipe. Over watering of a tank or excess rainfall caused an overflow through the vertical PVC pipe so that a constant water table depth was maintained in each tank. Consequently, all six pots in a particular tank experienced the same water level. There were 14 stock tanks containing 84 large pots.

In the 1999 study, two sugarcane cultivars were studied: 'CP 72-2086' (Miller et al. 1984) and 'CP 70-1133' (Rice et al. 1978). In 2000, there were two experiments: one experiment included CP 70-1133 and 'CP 85-1308' (Tai et al. 1995), and the second experiment of cyclic flooding was done only with CP 70-1133. These three cultivars ranged from progressively more (CP 85-1308) to less (CP 70-1133) high water-table tolerant (CP 85-1308), as reported by Glaz and colleagues (2002). For both years, 8 to 10 cm stalk sections used as vegetative "seed pieces" were prepared by cutting mature stalks at approximately 2.5 cm below each node and 6 cm above each node. Seed pieces were then soaked for 30 min in 52°C water. In 1999, the seed pieces were germinated by standing them upright on two to three pieces of wet filter paper in small tubs placed in a greenhouse. Seven days later (16 March 1999), three seed pieces exhibiting bud swelling and root formation were planted in each large PVC pot. On 5 April 1999, plants were thinned to one plant per pot. In some cases where no plants emerged, young plants were transplanted. For CP 70-1133, a plant was successfully established in all pots, while for CP 72-2086, there were a few missing plants. For the 2000 experiment, approximately 5 d after germination on wet filter paper (15 March 2000), the seed pieces were planted into round (10.2 cm diameter) peat pots containing soil from the top level of the muck field soil. The peat pots were kept in a greenhouse until 12 April when uniform plants were selected and transplanted into the large PVC pots in the stock tanks.

An irrigation dripper was placed in each pot and all pots were watered daily to excess. The overflow design (vertical PVC pipe) for each tank allowed the water-table depth to be maintained at a specific and constant height within a tank. Fertility was maintained in each pot by applying 250 mL of nutrient solution at a concentration of 3.5 g L^{-1} Miracle-Gro (15-30-15, Scotts Miracle-Gro Products, Inc., Port Washington, NY) approximately every two weeks.

Treatments

The objective of the 1999 experiment was to document the response of sugarcane to the imposition of a high, long-term water table and a flooding treatment at three times during the season. The 14 stock tanks were assigned to two sugarcane cultivars, two water table treatments, and three initiation dates. In addition, a 45 cm water-table depth, i.e., control treatment, was maintained for each cultivar throughout the experiment ($(2 \times 2 \times 3) + 2$). The high water-table treatment held the water depth in the tank at 15 cm below the soil surface, and the flooding treatment held the water surface at 5 cm above the soil surface. All plants were grown on a 45 cm water table until the initiation of each treatment at three times during the growing season. The first initiation date was 4 April (19 d after transplanting), which exposed the plants to nearly a season-long treatment. The second initiation date was 11 June (87 d after transplanting) to emulate the growth stage when frequent summer precipitation usually begins in South Florida. The third initiation date was 26 July (132 d after transplanting) to match the beginning of the active hurricane season in South Florida when very large amounts of precipitation from tropical storms are possible. All treatments were maintained until plant harvest on 15–16 November, resulting in total treatment durations of 232, 164, and 119 d, respectively.

There were two experiments in the 2000 study. The first involved a repetition of the 1999 experiment by imposing continuous water-table depth treatments on CP 70-1133 and CP 85-1308 beginning on 9 June 2000 (58 d after transplanting). The three treatments were 45 cm water table depth below the soil surface, 15 cm depth below the soil surface, and flood at 5 cm above the soil surface. Hence, six tanks (2 cultivars × 3 depths) were used in this experiment. The treatments were maintained until harvest on 22–23 November for a total duration of 158 d.

The second experiment in 2000 examined plant responses to intermittent flooding for durations of 3, 6, 10, or 14 d in successive 3 week cycles. Only CP 70-1133 was used in this test. All treatments were initiated on 9 June 2000 and continued on 3 week cycles until harvest for a total of eight cycles. During the flooding phase of each cycle, water level in the tank was raised to 5 cm above the soil surface. Based on the duration of each flood treatment, water in the tanks was allowed to drain on the appropriate date to water-table depths of either 15 cm or 45 cm. The lowered water table was maintained for the balance of the 3 week period. Hence, eight tanks (4 flood durations × 2 lowered water tables) were used in this experiment.

Analysis Procedures

At the end of the experiment, stalk number was recorded. All stalks in each pot were cut at soil level and at the first full dewlap from the top. Leaves were stripped from the stalks and total stalk fresh weight per pot (cane yield) was determined. All stalks were then milled to extract juice and determine commercial recoverable sucrose (CRS), measured as g sucrose kg^{-1} cane, calculated using a previously described procedure (Legendre 1992). In the 2000 experiments, after harvesting the shoots, the soil column was removed from each of the PVC pots. For the most part, the soil column simply slid out of the pot. Once out of the pot, the distance from the soil surface to the bottom of the root mass was measured. The bottom of the root mass was clearly defined, as the soil below the bottom of the root mass easily crumbled away, whereas in the rest of the soil column the dense root mass held the soil in place. Linear regressions were conducted using Prism 5.0 (GraphPad Software Inc., La Jolla, CA).

RESULTS

Continuous Water Table Depths

In the 1999 experiment, the mean cane yield for CP 72-2086 ranged from a low of 0.3 kg for the treatment with the longest duration of flooding (232 d) to a high of 2.9 kg for the 15 cm water-table depth of moderate duration (164 d, Figure 1A). For CP 70-1133, these same two treatments also produced the minimum (0.4 kg) and maximum (2.5 kg) cane yield (Figure 1B). When compared with the continuous 45 cm water-table depth (251 d at 45 cm), for CP 72-2086 the 164 d and 232 d duration 15 cm water tables had greater cane yields and the 119 d duration 15 cm water table yields were only slightly less (Figure 1A). For CP 70-1133, all three 15 cm water-table durations had greater cane yield than the continuous 45 cm water table (Figure 1B). For CP 72-2086, the regression line across all three durations at the 15 cm water table was significantly different than zero ($P = 0.03$), although the r^2 was relatively low ($r^2 = 0.31$). For CP 70-1133, the regression line across all three durations at the 15 cm water table was not significantly different than zero ($P = 0.33$). Together, these data indicate that the different durations at the 15 cm water table had no negative effect on cane yield.

The long-term flood treatments on both cultivars in 1999 resulted in progressively lower cane yield as flood duration increased (Figure 1). Yield decreased by 11.1 and 7.8 g pot^{-1} d^{-1} of flood duration for CP 72-2086 ($r^2 = 0.78$, $P < 0.001$) and CP 70-1133 ($r^2 = 0.78$, $P < 0.001$), respectively.

Stalk number differed between cultivars and in response to flooding (data not shown). Overall, the stalk number of CP 72-2086 tended to be greater than that of CP 70-1133. Except for flooded treatments, CP 72-2086 tended to have approximately one more stalk per pot than CP 70-1133. For both CP 72-2086 and CP 70-1133, differences in stalk number among various durations at the 15 cm water table were similar to the differences in stalk fresh weight. The 15 cm water-table treatments had little effect on stalk number (i.e., the slope of the regression line was not significantly different from zero [$P < 0.05$] for either cultivar). In the flood treatment, however, there was decreased stalk number with increasing duration of flooding for both cultivars. For CP 72-2086, the regression analysis indicated there was a loss of 0.03 stalks per day of flood ($r^2 = 0.82$, $P < 0.001$), whereas for CP 70-1133 the decrease was only 0.01 stalks per day ($r^2 = 0.33$, $P < 0.05$). The regression-line slopes for CP 72-2086 and CP 70-1133 were significantly different ($P < 0.01$), indicating a differing response to flooding duration.

Across both cultivars and all treatments, CRS ranged from 118.4 to 141.5 g kg^{-1} (data not shown). Linear regressions detected no significant response of CRS across all durations at the 15 cm water-table depth, for either CP 72-2086 or CP 70-1133 (i.e., no significant deviation from linearity [$P > 0.05$] but the slope of the line was not significantly different than zero [$P = 0.30$ or greater]). The same response was found for CP 72-2086 in the flooded treatment; however, for CP 70-1133 the slope of the regression line (0.19 ± 0.01) was significantly different from zero ($P = 0.04$). For CP 70-1133, the trend was for increasing CRS with increasing duration of the flooded treatment.

In the 2000 experiment, 158 d of either a 15 cm water table or flooding did not show any significant effect on cane yield (Figure 2A) or stalk number (Figure 2B) for both CP 70-1133 and CP 85-1308. However, numerically cane yield did increase under the continuous 15 cm water-table treatment and decrease under the continuous flood treatment for both cultivars. One

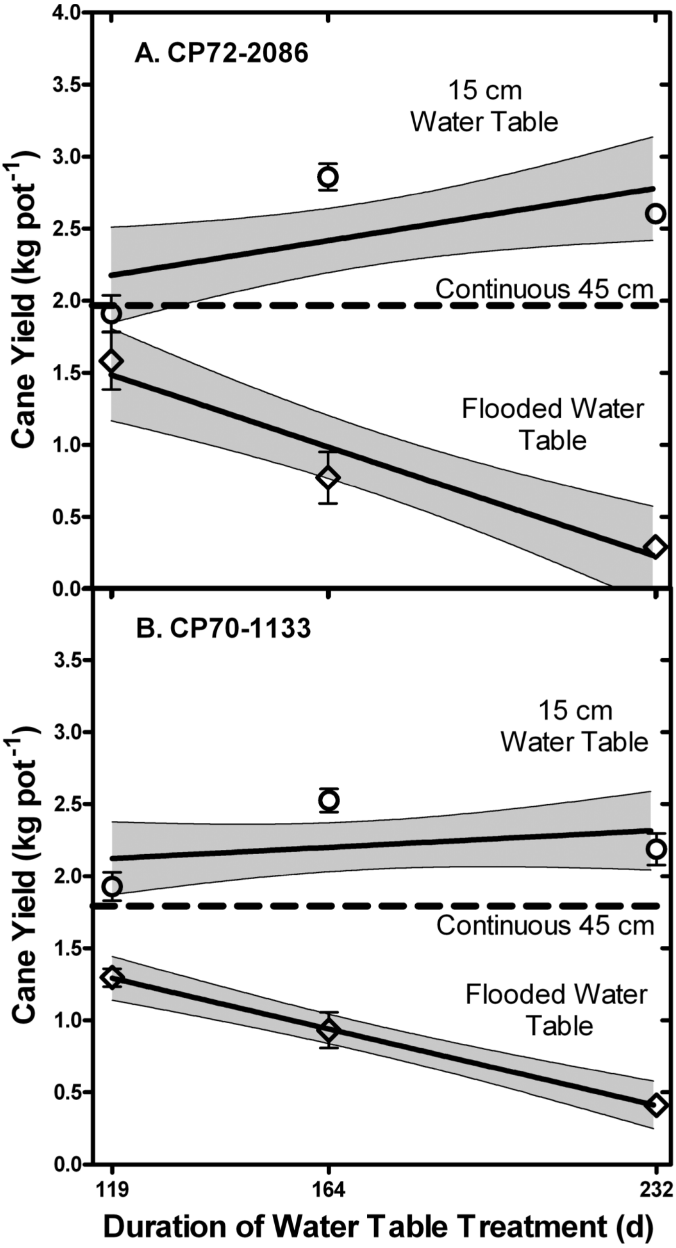

FIGURE 1 Cane yield (total stalk fresh weight, kg pot^{-1}) for CP 72-2086 and CP 70-1133 in the 1999 experiment. The horizontal dashed line for each genotype indicates the mean of the continuous 45 cm water-table depth. Error bars indicate the standard errors of the mean of each data point, and the gray areas represent the 95% confidence intervals of the regression lines.

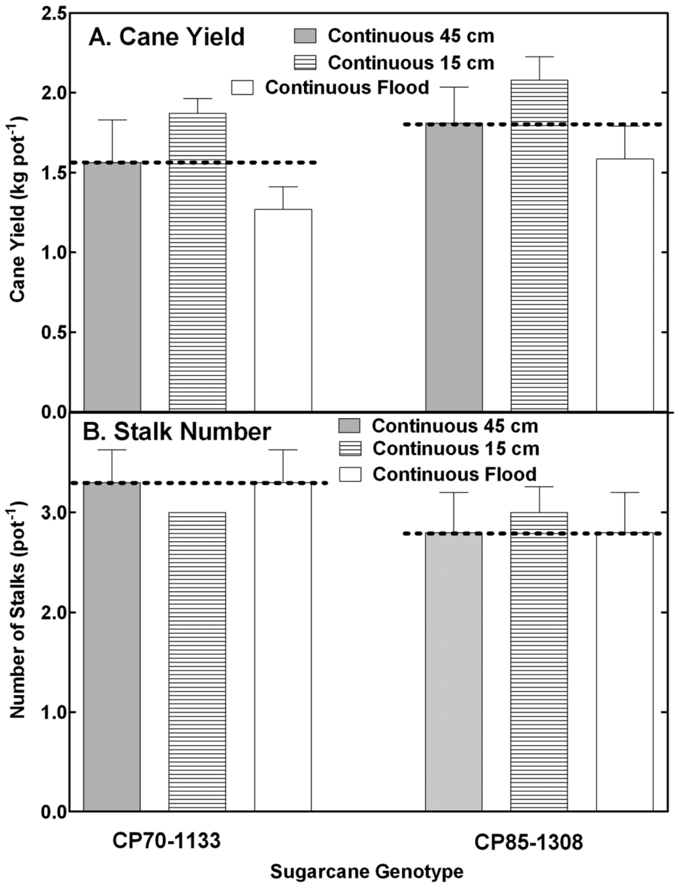

FIGURE 2 Cane yield (total stalk fresh weight, kg pot^{-1}) and number of stalks pot^{-1} for CP 70-1133 and CP 85-1308 in the three continuous treatments of the 2000 experiment. The horizontal dashed line for each genotype indicates the mean of the continuous 45 cm water-table depth. Error bars indicate the standard errors of the means.

possibility for the lack of statistical difference is that the muck soil in the 2000 study provided nutrients even under continuous flood in contrast to the sandy soil used in 1999 so that mass accumulation was not inhibited in 2000. Stalk number was also not altered by the flood treatment. These results indicate that under some conditions, the mass accumulation of each of these two sugarcane cultivars is insensitive to prolonged 15 cm water table and flooding.

Intermittent Flooding

Because intermittent rains makes it virtually impossible to sustain a fixed water table in the field, the second component of the 2000 experiment was designed to examine the response to various durations of intermittent flooding within

3 week cycles. Following flood treatments of various durations, the water table was returned to a depth of either 15 or 45 cm below the soil surface. These two cyclic treatments had remarkably similar effects on cane yield and stalk number (Figure 3). For both the intermittent flood/15 cm depth and the intermittent flood/45 cm depth, the regression lines (Figure 3) were not significantly different than zero ($P = 0.26$ and $P = 0.27$, respectively) and were not significantly different from one another (slope, $P = 0.14$ and intercept, $P = 0.46$). Similarly, for CRS, neither the intermittent flood/15-cm depth nor the intermittent flood/45 cm depth regression line was significantly different from zero ($P > 0.05$, data not shown), indicating no detectable effect of the treatments on sugar content. These results are consistent with the continuous flood experiment in that there was no significant difference between individual flood treatments.

Regression of cane yield on flood durations of 6, 10, and 14 d (i.e., excluding the 3 d flood duration) indicated decreases of 61.0 g fresh weight pot^{-1} ($r^2 = 0.38$, $P = 0.01$) and 69.0 g fresh weight pot^{-1} ($r^2 = 0.39$, $P = 0.01$) for each day the flood persisted beyond 6 d for water tables of 15 and 45 cm, respectively. There was no significant influence of the intermittent flood treatments on stalk number. For both the intermittent flood/15 cm depth and the intermittent flood/45 cm depth, the regression lines were not significantly different than zero ($P = 0.21$ and $P = 0.22$, respectively) and were not significantly different from one another (slope, $P = 0.89$ and intercept, $P = 0.60$).

Rooting Depth

There was a significant impact of water-table treatment on rooting depth in 2000 (Figure 4). Maintenance of a water table at 15 cm below the soil surface or flooded conditions resulted in much shallower rooting depth than observed in the control treatment (continuous 45 cm water table). Generally, in the high water-table treatments, roots were observed to exist to a depth of roughly 15 cm deeper than the water table for both cultivars. The roots in the treatment with a water table of 15 cm below the soil surface were found to exist roughly 30 cm in the soil, which made a reasonable soil volume available to the plants. Flooding at 5 cm above the soil surface resulted in root depths of approximately 10 cm in the soil.

Flooding alternating with a 15 cm water table in the 2000 experiment still resulted in substantial decreases in rooting depth as compared with a continuous 45 cm water table (Figure 5A). Flooding for as little as 3 d when alternated with an 18 d period of 15 cm water table resulted in a decrease of rooting depth to about 70% of the continuous 45 cm water-table treatment. Increasing duration of the flood period alternated with a 15 cm water table resulted in a decrease in rooting depth of 1.2 cm per day of flood ($r^2 = 0.74$, $P < 0.001$).

Periods of flooding alternating with a water table below the soil surface in the 2000 experiment allowed a greater rooting depth than observed in

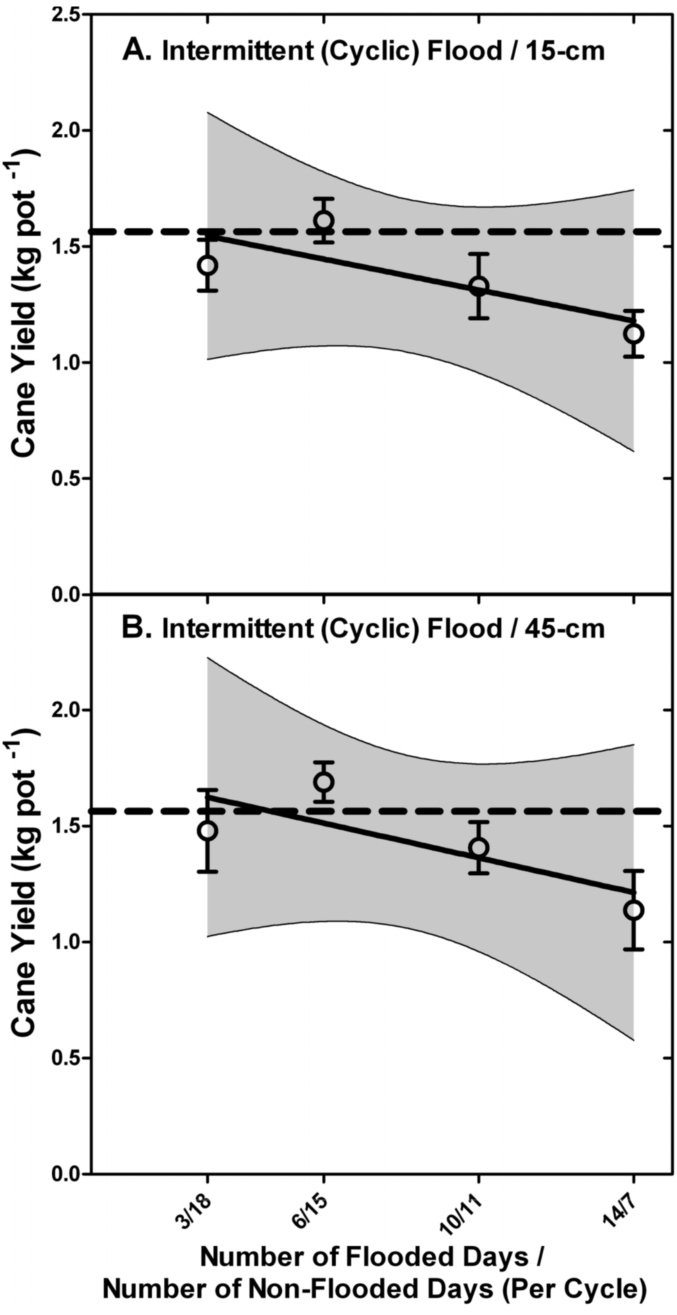

FIGURE 3 Cane yield (total stalk fresh weight, kg pot^{-1}) of CP 70-1133 for the cyclic flooded/15 cm and the cyclic flooded/ 45 cm treatments in the 2000 experiment. The horizontal dashed line for each genotype indicates the mean of the continuous 45 cm water-table depth. Error bars indicate the standard errors of the means, and the gray area represents the 95% confidence interval of the regression lines.

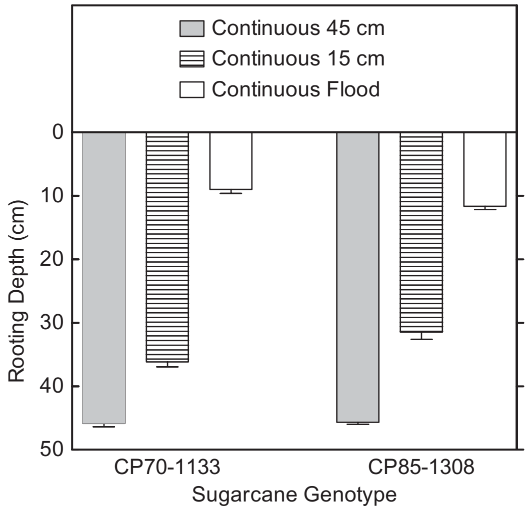

FIGURE 4 Rooting depths for CP 85-1308 and CP 70-1133 in the 2000 experiment for the three continuous treatments. Error bars indicate the standard errors of the means.

the continuous flood treatments in 1999. Flooding for only 3 d or 6 d, followed by a 45 cm water table, resulted in no suppression of rooting depth (Figure 5B). Even a 10 d flood, followed by 11 d of a 45 cm water table, resulted in only a modest loss in rooting depth. Nonetheless, across all treatments in both water-table depths there was a linear trend of reduced rooting depth with increasing number of flooded days in a cycle (15 cm water-table depth $r^2 = 0.85$; 45 cm water table-depth $r^2 = 0.80$; Figure 5). Rooting depth for the 14 d flood/7 d 45 cm water table caused the rooting depth to be about half of the control with a continuous water table at a 45 cm depth. Between the two water-table depths (15 and 45 cm), there was no significant difference ($P = 0.85$) in the slopes of the regression lines, indicating a similar response to flood durations at both water-table depths.

DISCUSSION

Overall, the cane yield results in these experiments indicated that sugarcane tolerates high water tables well. For all three tested cultivars, a water table continuously maintained at 15 cm below the soil surface had no adverse effect on cane yield (Figures 1 and 2) or stalk number (data not shown). While root depth was lessened by the 15 cm water-table treatment, roots still reached a depth of approximately 30 cm (Figure 4). This decreased rooting depth did not inhibit stalk growth under these experimental conditions. These results are consistent with observations of Glaz and colleagues (2002) on sugarcane growth in the field during June through October when a 15 cm

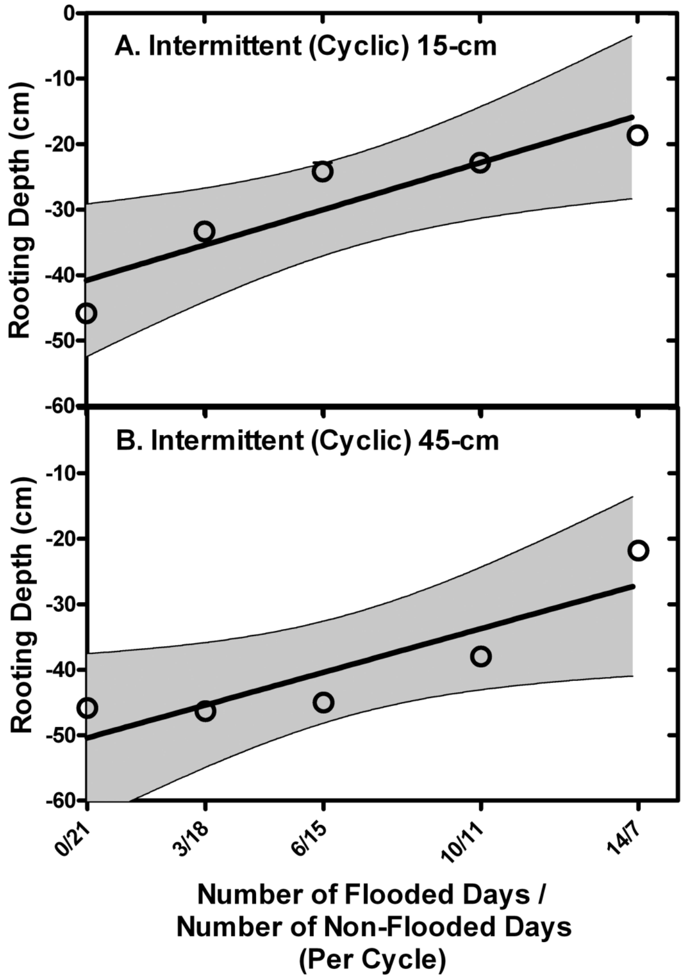

FIGURE 5 Rooting depths for CP 85-1308 and CP 70-1133 in the 2000 experiment for the combination of flooded days followed by non-flooded days at the 15 or 45 cm water-table depths. The zero flooded days followed by 21 non-flooded days (0/21) represents a control at a continuous 45 cm water-table depth. Error bars indicate the standard errors of the means, and the gray area represents the 95% confidence interval of the regression lines.

water table was maintained. They found that for five of the nine cultivars tested, there was no loss in cane yield. In fact, the results of our 2000 experiment indicated that even an intermittent flood of 3 or 6 d when cycled with a 15 cm water table sustained cane yield and stalk number equivalent to the control with a 45 cm water table (Figure 3). These results concur with those of Glaz, Morris, and Daroub (2004) for a sugarcane genotype that had constitutive stalk aerenchyma; however, they found substantial yield losses for a genotype that did not form constitutive stalk aerenchyma and was exposed to similar water treatments.

The impact on sugarcane growth of continuous flood was mixed in these experiments. Long-term floods of 232 d and 164 d on sandy soil in the 1999 experiment inhibited stalk growth of CP 72-2086 and CP 70-1133 (Figure 1). A flood of 119 d in 1999 also inhibited stalk growth of CP 70-1133, but the cane yield was not significantly decreased for CP 72-2086 compared with its yield under the 45 cm water-table treatment. A flood duration of 158 d in 2000 when the plants were grown on a muck soil did not result in a loss in cane yield for either of the two tested cultivars (Figure 2).

One possibility of overcoming any possible negative influence on cane yield would be to have a temporal management of water table by allowing the crop to be flooded only intermittently. The experiment in 2000 examined possible management solutions that included various intervals of flooding. There was no decrease in cane yield among the durations tested for the cycling between flooding and a lowered water table (Figure 3). This was true whether the water table was lowered to 15 cm or 45 cm. However, regression analysis indicated that flooding lasting more than 6 d had the potential for decreasing cane yield. Glaz and Gilbert (2006) reported a yield increase by flooding for 2 d and draining for 12 d in repeated cycles in the plant-cane and first-ratoon crops. Based on these results, field experiments should be established under field conditions to determine if sugarcane can readily tolerate floods lasting up to 6 d without yield loss and to investigate potential genotypic differences in short-duration flood tolerance.

Overall, we found little or no effect on CRS in any of the treatments evaluated during the two years of this study. Others have reported inconsistent effects of shallow-water-table depths on CRS. Glaz and Gilbert (2006) reported that as non-flooded water tables became increasingly shallow, CRS increased in the plant-cane and first-ratoon crops but decreased in the second-ratoon crop. Glaz (2007) reported that increasing durations of flood from 0 to 20 d, imposed about 6 weeks prior to harvest, resulted in a linear reduction of CRS from about 135.0 to 132.5 g kg^{-1} in the plant-cane crop but did not affect CRS in the first-ratoon crop. All of the experiments in our study would be considered a plant-cane crop.

Rooting depth was clearly affected in both cultivars studied because of continuous high water tables (Figure 4). However, rooting depth indicated that roots survived in approximately the top 15 cm of the water-saturated zone. Root survival in saturated soil is likely possible in sugarcane because of the presence of aerenchyma in roots (Artschwager 1925; Van Dillewijn 1952; Ray, Miller, & Sinclair 1996; Van Der Heyden, Ray, & Nable 1998). Aerenchyma may ameliorate anaerobic conditions in saturated soil by serving as a pathway for oxygen from the aerial part of the plant to the roots. Based on results of Glaz and colleagues (2004), aerenchyma formation in the stalk also plays a role in sugarcane flood tolerance. The root density/activity in the long-term flood treatment was apparently sufficient in this experiment to provide the nutrients and water needed to sustain stalk growth without any inhibition caused by the high water table.

Rooting depth was greater because of the cycling between flooding and a lowered water table than in a continuous flood treatment. A flood of up to 6 d, followed by a 45 cm water table, resulted in a depth of rooting equivalent to the treatment in which the water table was maintained continuously at 45 cm (Figure 5). Maintaining the water table at 15 cm following the flooding, however, decreased rooting depth for all durations of flooding. Increasing duration of flooding combined with the 15 cm water table resulted in a steady decrease in rooting depth.

Based both on the root-depth data and the changes in stalk fresh weight with increasing duration of flooding, a prudent conclusion is that flooding longer than about 6 d should be avoided. Water-table depth following flooding had a large influence on the depth of rooting. Rooting-depth differences between the 15 cm and 45 cm water table following flooding did not cause differences in stalk weight between the two water-table-depth treatments in these pot experiments. However, under field conditions, deeper rooting may be more important as it reduces the chances of lodging or uprooting of plants before or during harvest.

CONCLUSIONS

These pot experiments demonstrated that flooding for long durations could severely reduce cane yields but that a continuous high water table (15 cm water-table depth) did not decrease yields and in one year it actually increased cane yield compared with a 45 cm water-table depth. Intermittent flooding of up to 6 d, followed by lowered water tables, did not decrease yields or adversely affect CRS. These results indicated that growing sugarcane under conditions of repeated short-duration flooding could allow a management option of cyclical retention of flood water on fields, resulting in little or no adverse effects on potential sugarcane yield. However, rooting depth was inhibited by high water tables and flood durations greater than 11 d. A management scheme allowing greater retention of water on sugarcane fields and encouraging sufficient rooting depth could be an important approach for sustaining sugarcane yields while decreasing nutrient movement to neighboring ecosystems and for minimizing subsidence of organic soils.

REFERENCES

Artschwager E. 1925. Anatomy of the vegetative organs of sugar cane. *J. Agri. Res.* 30:197–241.

Deren C.W., G.H Snyder. J.D. Miller, and P.S. Porter. 1991. Screening for and heritability of flood-tolerance in the Florida (CP) sugarcane breeding population. *Euphytica* 56:155–160.

Gilbert R.A., C.R. Rainbolt, D.R. Morris, and J.M. McCray. 2008. Sugarcane growth and yield responses to a 3-month summer flood. *Agric. Water. Man.* 95:283–291.

Glaz B. 2007. Sugarcane response to month and duration of preharvest flood. *J. Crop Improve.* 20(1/2): 137–152.

Glaz B., S.J. Edme, J.D. Miller, S.B. Milligan, and D.G. Holder. 2002. Sugarcane cultivar response to high summer water tables in the Everglades. *Agron. J.* 94:624–629.

Glaz B., and R.A. Gilbert. 2006. Sugarcane response to water table, periodic flood, and foliar nitrogen on organic soil. *Agron. J* 98:616–621.

Glaz, B., D.R. Morris, and S.H. Daroub. 2004. Periodic flooding and water table effects on two sugarcane genotypes. *Agron. J.* 96:832–838.

Kang M.S., G.H. Snyder, and J.D. Miller. 1986. Evaluation of *Saccharum* and related germplasm for tolerance to high water table on organic soil. *J. Am. Soc. Sugar Cane Technol.* 6:59–63.

Legendre, B.L. 1992. The core/press method for predicting the sugar yield from cane for use in cane payment. *Sugar J.* 54(9): 2–7.

Miller J.D., P.Y.P. Tai, B. Glaz, J.L. Dean, and M.S. Kang. l984. Registration of 'CP 72-2086' sugarcane. *Crop Sci.* 24:2l0.

Omary, M., and F.R. Izuno. 1995. Evaluation of sugarcane evapotranspiration from water table data in the Everglades Agricultural Area. *Agri. Water Manage.* 27:309–319.

Ray J.D., J.D. Miller, and T.R. Sinclair. 1996. Survey of aerenchyma in sugarcane roots. Fifth Symposium, International Society of Root Research. July 14–18, 1996. Clemson, SC.

Rayment, G. 2002. Water quality pressures and status in sugar catchments, exposure draft +: Water quality compilation. Townsville, Queensland, Canada: Sugar CRC. Available online at http://www.gbrmpa.gov.au/_data/assets/pdf_file/0014/7511/crc_sugar_report.pdf.

Rice E.R., J.D. Miller, N.I. James, and J.L. Dean. 1978. Registration of CP 70-1133 sugarcane. *Crop Sci.* 18:526.

Shih S.F., B. Glaz, and R.E. Barnes Jr. 1998. Subsidence of organic soils in the Everglades agricultural area during the past 19 years. *Soil Crop Sci. Soc. Flor. Proceed.* 57:20–29.

Shih S.F., E.H. Stewart, L.H. Allen Jr., and J.W. Hilliard. 1978. Variability of depth to bedrock in Everglades' organic soil. *Soil Crop Sci. Soc. Flor. Proceed.* 38:66–71.

Snyder, G.H., H.W. Burdine, J.R. Crockett, G.J. Gascho, D.S. Harrison, G. Kidder, J.W. Mishoe, D.L. Myhpe, F.M. Pate, and S.F. Shih. 1978. Water table management for organic soil conservation and crop production in the Florida Everglates. Bull. Eol Agric. Exp. Stn., Inst. of Food and Agric. Sci., University of Florida, Gainesville, Florida. 22 p.

Snyder, G.H. 1994. Soils of the EAA. In *Everglades agricultural area (EAA): Water, soil, crop, and environmental management*, eds. A.B. Bottcher and F.T. Izuno, pp. 27–41. Gainesville, FL: University Press of Florida.

Snyder G.H., and J.M. Davidson. 1994. Everglades agriculture: Past, present and future. In *Everglades: The ecosystem and its restoration*, eds. S. Davis and J. Ogden, pp. 85–115. Delray Beach, FL: St. Lucie Press.

Srinivasan K., and M.B.G.R. Batcha. 1963. Performance of clones of *Saccharum* species and allied genera under conditions of water-logging. *Proceed. Int. Soc. Sugar Cane Technol.* 11:571–577.

Stephens J.C., L.H. Allen Jr., and E. Chen. 1984. Organic soil subsidence. *Rev. Eng. Geol.* 6:107–122.

Tai. P.Y.P., J.D. Miller, C.W. Deren, B. Glaz, J.M. Shine Jr., and J.C. Comstock. 1995. Registration of 'CP 85-1308' sugarcane. *Crop Sci.* 35(4): 1213.

Van Der Heyden, C., J.D. Ray, and R. Nable. 1998. Effects of waterlogging on young sugarcane plants. *Australian Sugarcane* 2:28–30.

Van Dillewijn, C. 1952. *Botany of sugarcane*. Waltham, MA: The Chronica Botanica Co.